

A DYNAMIC MODEL OF FILAMENT ERUPTIONS AND TWO RIBBON FLARES

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INTRODUCTION

Two basically different models for the filament equilibrium by Kippenhahn and Schluter (1957) and Kuperus and Raadu (1974) have appeared in the literature. In both models the filament is considered to carry a current. The force balance in the Kippenhahn and Schluter model is between the downward force of gravity and the upward Lorentz force between the filament current and the horizontal component of the background field due to bipolar regions close to the filament. The way the current circuit is closed in the photosphere is not considered in this model. In the Kuperus and Raadu model the downward gravitational force is balanced by the upward Lorentz force on the filament current from the magnetic field of a virtual mirror current of opposite sign. The mirror current is situated below the photosphere and closes the circuit in their model.

A further analyses by van Tend and Kuperus (1978) added the force due to the horizontal component of the background field to the Kuperus and Raadu model. The background magnetic field is assumed to be due to bipolar regions near the filament, and has the opposite sign to the field in the Kippenhahn and Schluter model. An interesting argument is presented by van Tend and Kuperus, in which they show that in the magnetic field configuration they present the currents tend to merge above the neutral line. Van Tend and Kuperus also showed that there is a maximum current above which non-equilibrium of the filament exists. They argue that once the filament surpasses this maximum value for the current, an eruption results. They suggest that this is related to the mass ejection in a solar flare, filament disappearance before a flare and the disappearance brusque of the filament.

In order to obtain a better model which actually describes these phenomena, the evolution of the filament has to be considered in detail. A first attempt was recently presented by Kaastra (1985). Kaastra did not formulate the precise energy balance equations for the problem, as is done in the present work. He used the a semi-empirical velocity law for filaments, where he assumes a negligible acceleration of the filament. Kaastra closed his equations by using an assumption about the relation between the height and the current of the filament. Thus he was able to model the eruption of the filament itself. He further included the existence of a current sheet at the neutral point. In the absence of magnetic field, as is the

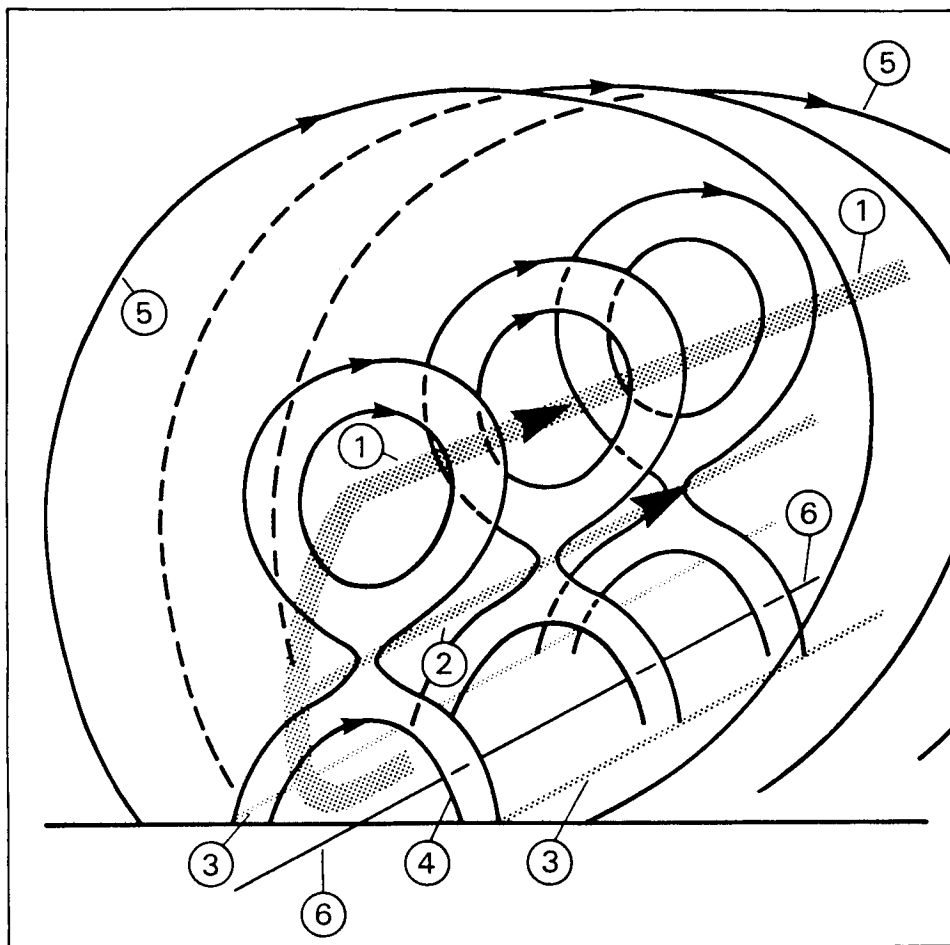


Fig. 1 A schematic of the field and current configuration during the filament eruption. 1. Filament current. 2. X-type neutral line. 3. Flare ribbons. 4. Closed fieldlines. 5. Background field. 6. Line of polarity reversal.

case at the neutral point, the rise of the current carrying filament induces a large electric field at the neutral point during the eruption. The resulting electron acceleration may then cause the hard X-rays observed during the flare. Kaastra compared his model to the May 16, 1981 flare, and found a good agreement with the observations.

In the present model not only the force balance, but also the energy balance of the filament is taken into account. Thus a fully closed system of equations is obtained, that describes the evolution of the filament, first in force equilibrium during the current build-up phase, then in the non-equilibrium phase before the eruption, and the eruption itself. A neutral point appears above the photospheric surface in the non-equilibrium phase, but long before the eruption. We find that although the filament itself may be in non-equilibrium, the evolution may still be slow up to the height where the eruption takes place. The eruption of the filament itself causes a large induced electric field at the neutral point which leads to the observed flare phenomena (see also Kaastra, 1985, for a detailed description)

THE DYNAMIC FILAMENT ERUPTION MODEL

We consider the filament as a line current, because the thickness of the filament is much smaller than its length or height above the photosphere.

Before the emergence of the X-type neutral point above the photosphere three forces act on the filament: gravity, the Lorentz force on the filament current due to the background field, and the Lorentz force on the filament current from the field generated by the chromospheric return current. After the emergence of the X-type neutral point above the photosphere two additional forces are present: the Lorentz force on the filament current from the field generated by the current located at the X-type neutral point, and Lorentz force due to the field generated by its return current in the chromosphere. Hence the force balance equation is:

mass filament \times acceleration = sum of Lorentz forces on the filament + gravity.

We assume that the mass of the filament is conserved, so that we do not have to solve the continuity equation.

It is suggested by observations that photospheric footpoint motions increase the shear of the field over the polarity-reversal line during the build-up phase. The stretching of field lines by footpoint motions gives rise to energy input into the filament, reflected in an increase in its current. Since the photospheric resistivity is high compared to that in the corona, we model the energy supply to the filament as an applied voltage with a large internal resistance in the circuit of the filament and return current. (For a discussion of the details of conversion of observed parameters to these circuit parameters, see Martens, 1986). The energy input into the filament circuit results in work done against the magnetic and gravitational forces acting on the filament, a change in its kinetic energy, and

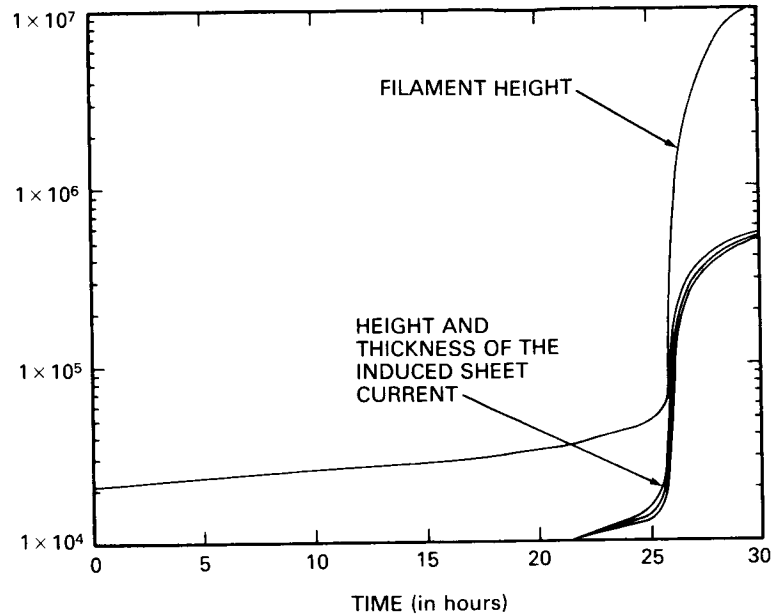


Fig. 2. The height of the filament and current sheet (in km) as a function of time (in hours). Zero time is the moment of emergence of the X-type neutral point above the photosphere, and lies in the non-equilibrium regime (no static solution).

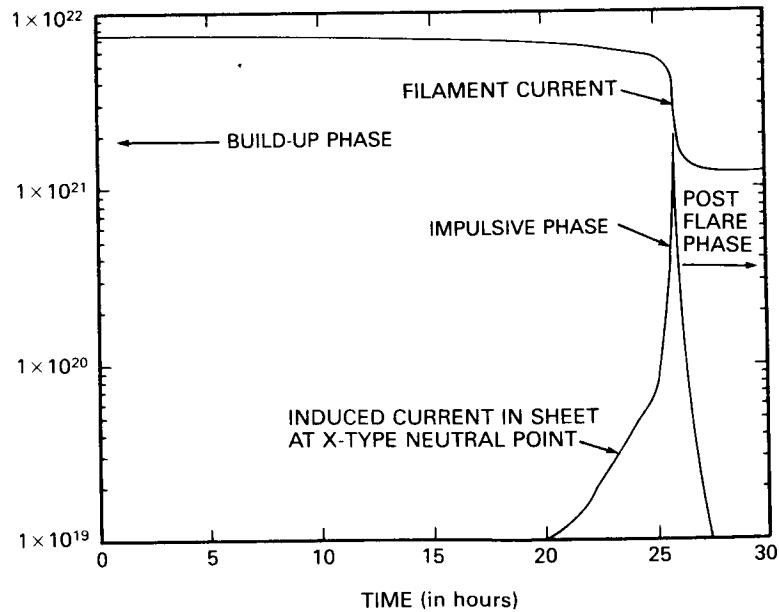


Fig. 3. The current of the filament and the induced current at the X-type neutral line (in units of statamp).

compensates for the resistive losses in the filament circuit.

The current sheet equations are 1. the force balance which determines the height of the sheet, 2. the energy equation describing the current induced by a change in the flux through the current sheet circuit. 3. the continuity equation which relates the induced current and the width of the current sheet (Syrovatskii, 1971, Kaastra, 1985). A detailed discussion will be published by Martens and Kuin (1986).

The equations describing the evolution of the filament are a sixth order system of ordinary non-linear equations, and are solved numerically. The initial filament height, velocity and current are found by assuming force-equilibrium. The parameters in the problem are the thickness of the filament, the depth and strength of the dipole representing the background field, the mass of the filament, and the resistivity in the filament and sheet circuit. Values derived for the May 16, 1981 flare were used.

RESULTS

In Figs. 2 and 3 the results for the May 16, 1981 flare are shown. The build-up of the filament current at earlier times was very slow. At $t=-40$ hours the current is at 0.96 of the current at $t=-10$ hours. Notice that the slow evolution continues, even when the filament is already in the non-equilibrium regime (past $t=-10$ hours). A neutral sheet is formed below the filament far before the eruption. The current induced by the change in flux through the current sheet circuit, due to the rising filament, is large enough for acceleration of the whole electron distribution (Kaastra, 1985), and this is the cause of the hard X-ray flare.

In order to make a comparison with the observations of a two-ribbon flare we need: -a magnetogram, -the height of the filament as a function of time, -an observational estimate of the energies in the mass ejection, the interplanetary blastwave, and the electromagnetic energy radiated away during the flare, -an estimate of the mass of the filament.

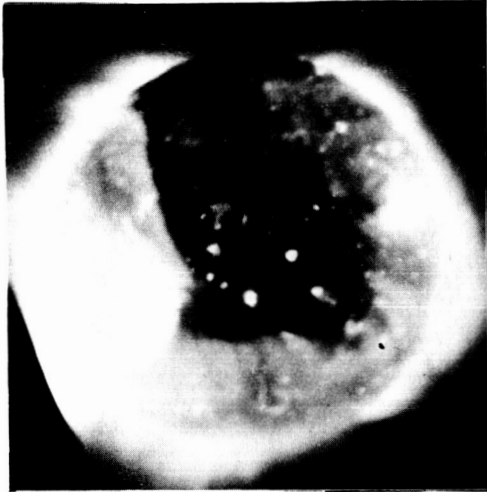
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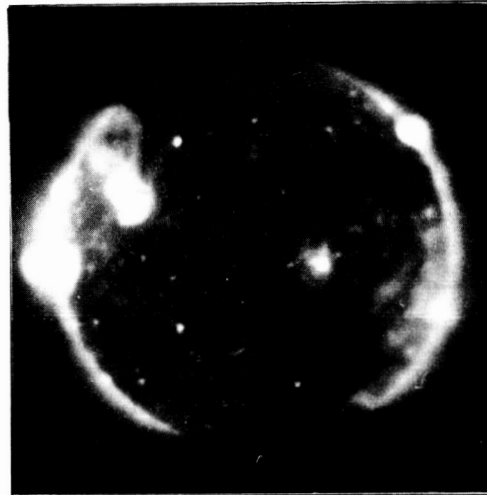
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CORONAL X-RAY OBSERVATIONS 1974 - 1981



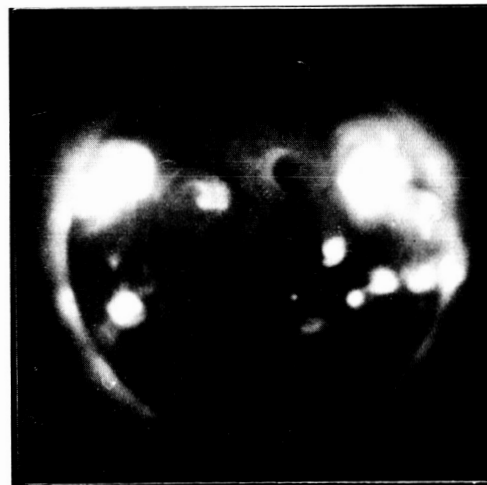
27 JUNE 1974



17 NOVEMBER 1976



31 JANUARY 1978



13 FEBRUARY 1981

High spatial resolution images of the solar corona obtained with an X-ray grazing incidence rocket payload. The images are representative of the variations in coronal structure and emission over the solar cycle. They were obtained near the end of the decline of Cycle 20 (1974), at activity minimum (1976), during the rise of Cycle 21 (1978), and just after the recent activity maximum (1981). Courtesy of the Solar Physics Group, American Science and Engineering, Inc.

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